(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 March 2004 (25.03.2004)

PCT

(10) International Publication Number
WO 2004/025291 A2

(51) International Patent Classification[7]: G01N 29/28

(21) International Application Number: PCT/GB2003/003986

(22) International Filing Date: 15 September 2003 (15.09.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/243,996 13 September 2002 (13.09.2002) US

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(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:
— *of inventorship (Rule 4.17(iv)) for US only*

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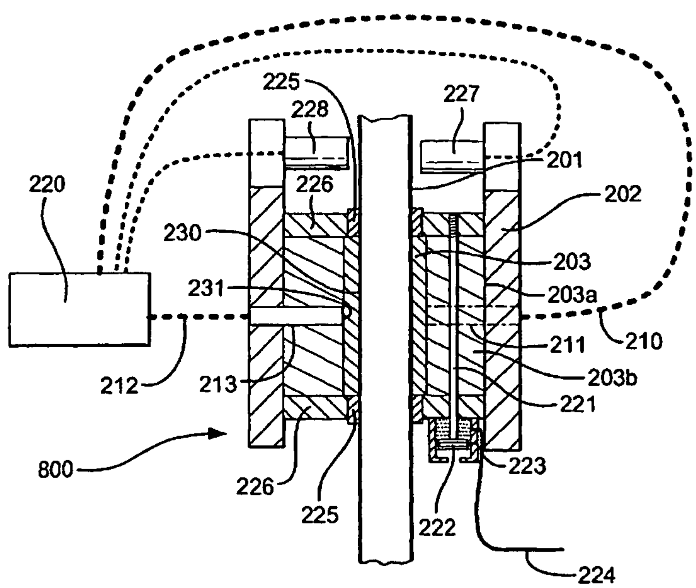
(54) Title: AN APPARATUS AND METHOD FOR INSPECTING A TUBULAR WITH ULTRASOUND



(57) Abstract: An apparatus for inspecting a tubular with ultrasound, which apparatus comprises means for mounting an ultrasonic transducer means on the apparatus adjacent an ultrasonic coupling means, the arrangement being such that, in use, ultrasound can be introduced into the tubular via said ultrasonic coupling means, characterised in that said ultrasonic coupling means comprises a deformable element and by means for applying a force to said deformable element to enhance the coupling between the ultrasonic transducer means and the tubular.

WO 2004/025291 A2

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

An Apparatus and Method for Inspecting a Tubular with Ultrasound

The present invention relates to an apparatus and method for inspecting a tubular with ultrasound, to a deformable element for use in the apparatus, to coiled tubing and to a method of manufacturing coiled tubing.

Generally coiled tubing comprises a long continuous pipe made from steel wound on a transport and storage spool. The tubing is straightened prior to pushing into a wellbore and recoiled to wind the tubing back onto the spool after use. Depending on the pipe diameter (e.g. 1" to 4.5") and the spool size, coiled tubing can range in length from about 610m (2000ft) to about 4570m (15000ft) or greater.

Coiled tubing is used in the oil and gas industry for a variety of purposes. For example it is used for completion and drilling where it offers several advantages over jointed strings of pipe. In both completion and drilling, trip time is reduced as connection time is eliminated. Furthermore as the pipe is continuous problems associated with fluid tightness of pipe joints are avoided.

However, a failure of coiled tubing either in a well or while being bent or straightened at the surface can have serious safety, environmental and/or economic impact. Whilst improvements have been made in the quality of materials, manufacturing processes and quality control of coiled tubing; modelling of fatigue damage due to the repeated bending and straightening; and handling and treatment of coiled tubing to inhibit corrosion and mechanical damage; the demands being placed on coiled tubing are increasing. For example, coiled tubing is now routinely required in well fracturing operations that utilise high pressures sufficient to crack the formation, and in acid stimulation to improve formation permeability

by reaction with or dissolving of substances in the formation. It will be appreciated that such high pressures and corrosive chemicals, together with repeated straightening and bending of the tubing are likely to reduce the mechanical integrity of the coiled tubing. Furthermore, coiled tubing may be worn when used in wells with chrome tubulars. It is therefore important to monitor the mechanical properties of the tubing so that it can be taken out of service after an economically worthwhile working life but before a failure.

Ultrasonic inspection apparatus have been proposed for coiled tubing. US-A-5 303 592 discloses an inspection head for continuous acoustic energy inspection of coiled tubing consisting of a generally cylindrical test head for receiving the tubing longitudinally therethrough while being sealed on each end to maintain fluid couplant circulation. A cylindrical test array is disposed within the head to receive the tubing while directing a plurality of radially aligned compressional wave acoustic sensors and single in-line, angularly oriented shear wave acoustic sensors. Analysis of the various signal returns facilitates derivation of ovality, inside and outside wall pitting, wall thickness, and transverse and/or longitudinal flaws.

Apparatus of the foregoing type relies upon water to provide the coupling medium between the ultrasonic transducers and the coiled tubing. A major problem with this is that very often, particularly when withdrawing coiled tubing from a well, it is dirty. This is turn makes the water dirty as the coiled tubing passes through the inspection head. This is highly undesirable as dirt in the water has a detrimental effect upon the reliability and accuracy of the apparatus. This means that the mechanical properties of the pipe cannot be accurately measured, which is important as explained

above. Furthermore the apparatus often needs to be used in harsh environments where the air temperature is well below zero, or liquid gases need to be passed through the coiled tubing. In such circumstances the water couplant has been known to freeze. This may result in a delay to the coiled tubing operation which is unacceptable. The apparatus of US-A-5 303 592 is not quick and easy to emplace and remove from a coiled tubing string as water tight seals must be ensured, and the water supplied to and drained from the apparatus before it can be used or removed.

It is apparent that there is a need for an improved ultrasonic test apparatus and method that alleviate at least some of the aforementioned disadvantages, which apparatus is relatively quick and easy to fit and remove to a coiled tubing string being inserted into or withdrawn from a wellbore for example.

According to the present invention there is provided an apparatus for inspecting a tubular with ultrasound, which apparatus comprises means for mounting an ultrasonic transducer means on the apparatus adjacent an ultrasonic coupling means, the arrangement being such that, in use, ultrasound can be introduced into the tubular via said ultrasonic coupling means, characterised in that said ultrasonic coupling means comprises a deformable element and by means for applying a force to said deformable element to enhance the coupling between the ultrasonic transducer means and the tubular. In this way the problems of dirty and freezing water are inhibited. The apparatus is also easier to fit to and remove from coiled tubing, for example. The means for applying a force may apply a compression force to the deformable element. The force may be applied directly or indirectly to the deformable element. When applied indirectly it may be applied via the ultrasonic

transducer means for example.

Further features are set out in claims 2 to 34 to which attention is hereby directed.

The deformable element may be such that, under application of force, it substantially conforms to the shape of the part of the tubular with which it is in contact and is pressed against a working face of the ultrasonic transducer means. In this way, ultrasonic coupling is enhanced between the ultrasonic transducer means and the tubular, and the deformable element can respond to changes in the shape of the tubular that can be detected by the ultrasonic transducer means. The deformable element may be a substantially elastic solid for example. The deformable element may also comprise any material capable of deformation or elastic deformation under pressure to substantially conform to a part of the tubular being inspected. For example it may be a substantially solid elastomeric material. Such a solid may be manufactured or formed into a shape substantially the same as the shape of the tubular to be inspected, with relatively little deformation taking place upon application of the force.

A packer element is typically used to seal around a pipe, separating the fluids in a well from the atmosphere. The apparatus may comprise a stripper packer element as the deformable element. Alternatively, a stripper packer apparatus can be adapted to house ultrasonic transducers. For example US-A-5 566 753 shows two types of coiled stripper packers. In the case of drilling with jointed pipe a stripper packer (e.g. US-A-4 486 025) and/or an annular blow out preventer ("BOP") and/or rotating BOP contains the packer element(s). In the case of hydraulic work-over (often known as "snubbing") operations, several types of sealing mechanisms containing packer elements may be used in the

present invention, including stripper bowls and annular BOPs, as are discussed for example in US-A-5 988 274. Stripper packer apparatuses useful with apparatus according to the present invention include, but are not limited to, those with pistons or rams that apply force either generally radially (at a right angle to the pipe) or generally in the direction of the longitudinal axis of the pipe.

The deformable element or packing element in the apparatus and method according to the present invention can be made of an elastomeric material such as, but not limited to, a polyurethane, a rubber compound, polypropylene, polytetrafluoroethylene, polyvinylchloride, plastisols, and Viton (TM) material. A polyurethane, such as a castable polyurethane, is particularly preferred for resistance to abrasion in combination with elastomeric properties. The elements may be composed of a single piece made of one or more elastomeric material(s), or may be composed of multiple pieces made of one or more elastomeric materials.

Many methods can be used to compress a packing element against the pipe to form a pressure seal. Techniques according to the present invention for inspecting pipe through an elastomeric element may be used in any of the aforementioned devices. These techniques may also, according to the present invention, be used in a device with an elastomeric element and compression apparatus built for performing pipe inspection which may or may not also serve as a pressure barrier.

A thin film of a fluid (e.g. grease or oil) may or may not be placed between the probe(s) and the element, and/or between the element and the pipe to further enhance the acoustic coupling.

To enhance the deformable element's ability to

transmit acoustic waves, multiple elastomeric materials can be used. For example, and not by way of limitation, the material between the UT probe(s) and the pipe may be selected for its ability to transmit acoustic waves, while the remaining material may be selected for its ability to form a pressure seal. The ultrasonic transducer(s) or a portion of them may be embedded in the element, affixed to it, or screwed into it.

According to another aspect of the present invention there is provided a deformable element for use in the apparatus as aforesaid.

According to another aspect of the present invention there is provided a method of inspecting a tubular with ultrasound, which method comprises the steps of: -

(1) introducing ultrasound with an ultrasonic transducer means into the tubular via an ultrasonic coupling means;

(2) receiving via the ultrasonic coupling means any ultrasound reflected from a part of the tubular and generating an output electrical signal representative thereof;

characterised in that said ultrasonic coupling means comprises a deformable element and by the step of applying a force to said deformable element to enhance the coupling between the ultrasonic transducer means and the tubular.

Further steps of the method are set out in claims 39 to 47 to which attention is hereby directed.

A further problem with which the present invention is concerned is the provision of reference points along a coiled tubing string that can be easily located. Such reference points would be useful to verify a depth or length measurement or to determine a location along a coiled tubing string. It would be useful to have such a reference point(s) detectable by ultrasonic apparatus.

According to another aspect of the present invention there is provided coiled tubing having a first wall thickness along the majority of its length, and provided with at least one portion of a second wall thickness different to said first, the second wall thickness useable as indication of the length of the coiled tubing that has been inserted into or withdrawn from a wellbore for example.

According to another aspect of the present invention there is provided a method of manufacturing coiled tubing, which method comprises the steps of folding a sheet of material of a first wall thickness and welding the two free sides to form a tubular, and providing portions of a second wall thickness different to said first at predetermined intervals along the length of the coiled tubing to serve as an indication of length when inserting or withdrawing the coiled tubing into or from a wellbore for example.

According to another aspect of the present invention there is provided a method for ultrasonically inspecting pipe, the pipe having a longitudinal axis, the method comprising compressing with a compressing force an elastomeric element between an ultrasonic probe apparatus of an ultrasonic pipe inspection system and a pipe to be inspected thereby forcing the elastomeric element against the pipe.

Preferably, the compressing force is applied generally in the direction of the longitudinal axis of the pipe.

Advantageously, the compressing force is applied radially against the elastomeric element.

Preferably, the method further comprises the step of placing a coupling fluid between the elastomeric element and the pipe.

Advantageously, the coupling fluid is from the group

consisting of water, oil and grease.

Preferably, the elastomeric element surrounds the pipe.

Advantageously, the elastomeric element is a packing element. Alternatively, the packing element is a stripper packer.

Advantageously, the compressing force is applied by at least one compressing member.

Preferably, the packing element is from the group consisting of a coiled tubing stripper packer, a drilling stripper packer, and a hydraulic workover stripper packer.

Advantageously, the ultrasonic probe apparatus is mounted in a housing, the elastomeric element within the housing.

Preferably, the ultrasonic probe apparatus is mounted on or embedded in a housing, the elastomeric element within the housing.

Advantageously, the elastomeric element is in contact with the ultrasonic probe apparatus.

Preferably, the ultrasonic probe apparatus is mounted within the elastomeric element.

Advantageously, the elastomeric element has an amount of acoustic transmission material and the ultrasonic probe apparatus is positioned between the acoustic transmission material and the pipe to be inspected.

Preferably, the ultrasonic probe apparatus comprises a plurality of spaced-apart ultrasonic probes between the elastomeric element and the pipe.

Advantageously, the elastomeric element comprises a first portion made of sealing material for sealing against the pipe and a second portion made of acoustic transmission material disposed between the ultrasonic probe apparatus and the pipe.

According to another aspect of the present invention there is provided a system for ultrasonically inspecting pipe, the pipe having a longitudinal axis, the system comprising

at least one ultrasonic apparatus for transmitting ultrasonic sound waves to a pipe to be inspected, for receiving reflected waves back from said pipe, and for producing signals indicative of a parameter of said pipe, the at least one ultrasonic apparatus having at least one ultrasonic probe,

control apparatus for controlling the at least one ultrasonic apparatus,

processing apparatus for processing signals from the at least one ultrasonic apparatus,

an elastomeric element for contacting the pipe and for contacting the at least one ultrasonic probe, the at least one ultrasonic probe located in or adjacent the elastomeric element, and

apparatus for applying compressive force to the elastomeric element.

Preferably, the elastomeric element is a stripper element of a stripper packer system.

Advantageously, the stripper packer system is from the group consisting of a coiled tubing stripper packer system, a drilling stripper packer system, and a hydraulic work-over stripper packer system.

Preferably, the at least one ultrasonic probe is mounted in a housing.

Advantageously, the at least one ultrasonic probe contacts the elastomeric element.

Preferably, the at least one ultrasonic probe is mounted within the elastomeric element.

Advantageously, the elastomeric element has an amount of acoustic transmission material and the at least one ultrasonic probe is positionable between the acoustic

transmission material and the pipe to be inspected.

Preferably, the at least one ultrasonic probe is a plurality of spaced-apart ultrasonic probes locatable between the elastomeric element and the pipe.

Advantageously, the compressing force is applied generally in a direction parallel to the longitudinal axis of the pipe.

Preferably, the compressing force effects radial compression of the elastomeric element.

Advantageously, the compressing force is applied by at least one compressing member.

According to another aspect of the present invention there is provided a system for ultrasonically inspecting pipe, the pipe having a longitudinal axis, the system comprising

at least one ultrasonic apparatus for transmitting ultrasonic sound waves to a pipe to be inspected, for receiving reflected waves back from said pipe, and for producing signals indicative of a parameter of said pipe, the at least one ultrasonic apparatus having at least one ultrasonic probe,

control apparatus for controlling the at least one ultrasonic apparatus,

processing apparatus for processing signals from the at least one ultrasonic apparatus,

an elastomeric element for contacting the pipe and for contacting the at least one ultrasonic probe, the at least one ultrasonic probe located in or adjacent the elastomeric element,

apparatus for applying compressive force to the elastomeric element,

wherein the elastomeric element is a stripper element of a stripper packer system,

wherein the stripper packer system is from the group consisting of a coiled tubing stripper packer system, a

drilling stripper packer system, and a hydraulic work-over stripper packer system, and

wherein the at least one ultrasonic probe is mounted in or on a housing, the elastomeric element within the housing.

According another aspect of the present invention there is provided a system for ultrasonically inspecting pipe, the system comprising a housing; a packer element in the housing, the packer element having an opening through which a pipe to be inspected is passable; at least one ultrasonic probe in or on the housing, said at least one ultrasonic probe useful in conjunction with an ultrasonic apparatus for inspecting pipe.

Preferably, the at least one ultrasonic probe is at least partially within the packer element.

According to another aspect of the present invention there is provided a method of indicating a location in a wellbore extending from an earth surface down into the earth, the method comprising

introducing a tubular string into a wellbore, the tubular string having a substantially uniform first wall thickness along its length and at least one second area of a second wall thickness, the first wall thickness different from the second wall thickness, the second wall thickness of the at least one second area sensible by wall thickness sensing equipment, the tubular string having a string location thereon a distance from the at least one second area,

sensing with the wall thickness sensing equipment the presence of the second wall thickness thereby indicating the presence of the at least one second area,

sending a signal from the wall thickness sensing equipment to processing equipment, and

determining with the processing equipment the position of the string location within the wellbore.

For a better understanding of the present invention reference will now be made, by way of example, to the accompanying drawings, in which: -

Fig. 1 is a schematic side cross-section of a first embodiment of an apparatus in accordance with the present invention in use;

Fig. 2 is a schematic side cross-section of an alternative elastomeric element and ultrasonic probe combination for use in an apparatus in accordance with the present invention, in use with coiled tubing;

Fig. 3 is a schematic side cross-section of a second embodiment of an apparatus in accordance with the present invention in use;

Fig. 4 is a schematic side cross-section of a third is embodiment of an apparatus in accordance with the present invention in use;

Fig. 5A is a schematic horizontal section of a fourth embodiment of an apparatus in accordance with the present invention in use;

Fig. 5B is a schematic side cross-section of the apparatus of Fig. 5A;

Fig. 6 is a schematic side cross-section of a fifth embodiment of an apparatus in accordance with the present invention in use;

Fig. 7 is a schematic horizontal section of a sixth embodiment of an apparatus in accordance with the present invention in use;

Fig. 8 is a schematic side cross-section along the line VIII-VIII of Fig. 7; and

Fig. 9 is a schematic graph of an output electrical signal from one ultrasonic transducer in an apparatus in accordance with the present invention, the graph showing voltage (y-axis) against time (x-axis).

Referring to Fig. 1 an apparatus generally identified by reference numeral 200 has ultrasonic (UT)

pipe inspection capabilities. A generally cylindrical hollow pipe 201 passes through a housing 202 with an elastomeric element 203 in a cavity 203a. The elastomeric element 203 surrounds the pipe and can be compressed by force or pressure 205 on a piston 204. UT probes 211 and 213 are affixed to or embedded in the housing 202. Electrical wires 210 and 212 from the probes 211 and 213, respectively, pass out of the housing 202 and to a UT control/processing system 220 (which may also display results) such as a computer. When the element 203 is subjected to a compressing force or pressure 205 (in a direction generally in the direction of a longitudinal axis of the pipe 201), the element 203 is compressed, including in a generally radial direction against both the UT probes 211 and 213 and against the pipe 201. This compressive loading enhances the acoustic coupling required for the sound wave to pass from the UT probes 211 and 213 to the pipe 201. The sonic coupling may be improved if the pipe 201 is coated with a fluid, e.g. but not limited to oil. Also, the coupling may be improved if a fluid such as grease is applied between the probes 211, 213 and the element 203, i.e., grease indicated at 231; and also applied between the element 203 and the pipe 201, i.e., grease indicated at 230. An end portion of each of the UT probes may extend slightly into the cavity 203a to insure good contact of the probes with the element 203 (e.g., as shown in Fig. 2). The elastomeric element 203 may be a stripper packer.

Referring to Fig. 2 a combination generally identified by reference numeral 300 comprises an elastomeric element 302 containing UT probes 311 and 313. The elastomeric element 302 may be a packing element of a stripper packer apparatus, or any of the elastomeric elements described herein. The probes 311, 313 are connected to and in electronic communication with a UT

inspection system (not shown, but like the system 220 of Fig. 2) by wires 310 and 312, respectively. The elastomeric element 302 may contain multiple regions or parts including a part 303. In one aspect the elastomer in the elastomeric element 302 is chosen for its sealing capabilities, and the material in the region or part 303 is chosen for its acoustic transmission capabilities. The part 303 may, according to the present invention, be a bladder or fluid bag. The inner end of each probe 311, 313 extends slightly into a cavity 303a that contains the elastomeric element 303.

Referring to Fig. 3 an apparatus generally identified by reference numeral 400 has UT inspection capability. A generally cylindrical hollow pipe 401 passes through a housing 402 with an elastomeric element 403 in a cavity 403a. The element 403 has an intermediate portion 414 which, in one aspect, is made of material that enhances acoustic transmission. The element 403 and its intermediate portion 414 surround the pipe and are compressed by force or pressure 405 on a piston 404. UT probes 411 and 413 are affixed to or embedded in a housing 402. Electrical wires 410 and 412 from the probes 411 and 413, respectively, pass out of the housing 402 and to a UT control/processing system 420 (like the system 220 in Fig. 2) such as a computer. When the element 403 is subjected to a compressing force or pressure 405 (in a direction generally in the direction of a longitudinal axis of the pipe 401), the element 403 and the intermediate portion 414 are compressed, including in a generally radial direction against both the UT probes 411 and 413 and against the pipe 401. This compressive loading enhances the acoustic coupling required for the sound wave to pass from the probe to the pipe. The sonic coupling may be improved if the pipe is coated with a fluid, e.g. but not limited to oil. Also,

the acoustic coupling may be improved if a fluid such as grease is applied between the probes 411, 413 and the element 403, i.e., grease indicated at 431; and also applied between the element 403 and the pipe 401, i.e., grease indicated at 430. An end portion of each of the UT probes may extend slightly into the cavity in which the element 403 is positioned to insure good contact of the probes with the element. The wall thickness of the pipe 401 varies with a thicker part 415 as compared to other parts of the pipe. Any tubular, pipe or CT herein may have one or more areas of rings of differing wall thickness.

Fig. 4 shows an alternative embodiment of the apparatus 400 of Fig. 5 that is generally identified by reference numeral 500, with like numerals indicating like parts. Intermediate portion 414a (like the intermediate portion 414 of Fig. 4) does not contact the pipe 401 and may, in certain aspects, be made of material that enhances acoustic transmission. A portion of an element 403a (like the element 403 of Fig. 4) is between the pipe 401 and the intermediate portion 414a.

Referring to Figs. 5A and 5B an apparatus generally identified by reference numeral 600 comprises radially movable rams 604a, 604b movable in a housing 602. Forces 605a, 605b on the rams 604a, 604b, respectively, move the rams. The rams apply a radial (normal to the longitudinal axis of pipe 601) force to an elastomeric element 603 in a housing cavity 603a. UT probes 611, 613 are each positioned within part of the housing 602 (but it is within the scope of this invention to position the probes in the elastomeric element 603 or to position them as are positioned any other probe disclosed herein and it is within the scope of this invention to use radially moving compressing members in any of the embodiments disclosed herein). The housing 602 is made of a plurality of parts

that can be assembled and disassembled. The UT probes 611, 613 are connected to a processing system (not shown, but like the system 220 of Fig. 2) by wires 610, 612, respectively.

Referring to Fig. 6 an apparatus generally identified by reference numeral 700 is an alternative embodiment of the system 200 of Fig. 2, with like numerals indicating like parts. UT probes 211a and 213a (like the UT probes 211 and 213, Fig. 2) are connected to the exterior of the housing 202. As shown, ends of the probes 211 and 213 project slightly into the housing 202; but it is within the scope of the present invention for the UT probes to be completely outside of or embedded in the housing 202. In certain aspects the housing 202 is made of material suitable for acoustic transmission. In certain aspects a metal housing, e.g., but not limited to, one made of steel, acts as a delay line.

Referring to Figs. 7 and 8 a sixth embodiment of the coiled tubing inspection apparatus is generally identified by reference numeral 800. The apparatus 800 is generally similar to apparatus 200 with like numerals indicating like parts. In this embodiment the housing 202 is constructed from steel in two semi-circular halves that are mounted together by a pair of nuts and bolts (not shown), one nut and bolt on each side of the housing 202 respectively. The apparatus 800 is about 0.22m (8.5″) long, 0.19m (7.5″) in diameter and weighs about 18kg (40lbs). One nut and bolt provides a pivoting action between the two halves around an axis parallel to longitudinal axes of the halves. In this way the housing is moveable between an open position for receiving coiled tubing to be inspected and a closed position in which coiled tubing can be inspected. The other bolt is provided with two latches (not shown) that, when the housing is in a closed position, serve to draw the two

halves together and hold the same in a clamped position.

In the closed position the housing 202 provides a cylindrical cavity 203a in which elastomeric elements 203 and 203b are mounted concentrically with respect to one another, the elastomeric element 203 being inside the elastomeric element 203b. Elastomeric element 203 is of generally solid cylindrical shape with a bore therethrough that is co-axial with the longitudinal axis of the element 203. The elastomeric element 203 has a thickness of 12.7mm (0.5″), a length of 63.5mm (2.5″) and is formed in two halves, each half being accommodated in a respective half of the housing 202. The inner surface of the elastomeric element 203 is substantially cylindrical so as to be generally circular in horizontal section (see Fig. 7). The outer surface of the elastomeric element 203 is provided with twelve flat portions around its circumference, each of which extends along its length, providing a suitably shaped interface for the twelve UT transducers. The elastomeric element 203 is made from polyurethane and has a Shore A hardness of 85. The applicant has found that a range of Shore A hardness of between about 80 and about 90 produces good results taking into consideration the mechanical properties required to achieve the desired functions of this material as stated herein. Details of the physical properties of the polyurethane of the elastomeric element 203 are set out in the following table: -

Physical Property	
Hardness, Shore A	85
Hardness, Shore D	32
Split Tear Strength, pli	275
Die C Tear Strength, pli	520
Tensile Strength, psi	7000
Ultimate Elongation, %	575

Break Set, %	10
100% Modulus, psi	725
200% Modulus, psi	1100
300% Modulus, psi	1500
Compression Set, %	35
Compression Deflection	
2% Deflection, psi	80
5% Deflection, psi	170
10% Deflection, psi	310
15% Deflection, psi	440
20% Deflection, psi	590
25% Deflection, psi	740
50% Deflection, psi	2150
Taber Abrasion, mg loss	8.5
NHS Abrasion, % Rubber standard	250

Such a polyurethane with these physical properties can be obtained from Esco Plastics Company, Texas, US (www.escoplastics.com) sold as formulation #E1539, and is manufactured by Anderson Development Company, Michigan, US (www.andersondevelopment.com).

The elastomeric element 203b is also of generally solid cylindrical shape with a bore therethrough that is co-axial with the longitudinal axis of the element 203b. The elastomeric element 203b is made from polyurethane and has a Shore A hardness of 60. The applicant has found that a range of Shore A hardness of between about 50 and about 80 produces good results taking into consideration the mechanical properties required to achieve the desired functions of this material as stated herein. The elastomeric element 203b has the following physical properties: -

Physical Property	
Hardness, Shore A	60
100% Modulus, psi	210
300% Modulus, psi	320
Tensile, psi	3000
Elongation	560
Tear, Die C, pli	180
Split tear, D-470, pli	50
Bashore resilience, %	53

Such a polyurethane with these physical properties can be obtained from Esco Plastics Company, Texas, US (www.escoplastics.com) sold as formulation #E1518.

As mentioned above the bore through the element 203b accommodates the elastomeric element 203 such that, when the housing is closed, they are arranged concentrically. The elastomeric element 203b is formed in two halves, each half being accommodated in a respective half of the housing 202. The outer surface of the elastomeric element 203 is substantially cylindrical so as to be generally circular in horizontal section (see Fig. 7). The inner surface of the elastomeric element 203 is provided with twelve flat portions around its circumference, each of which extends along its length, so as to conform substantially to the outer surface of the elastomeric element 203 described above. Twelve radial bores are formed around the circumference of the elastomeric element 203b, mid-way along its length each of which extend from the outer surface to the inner surface. Each bore is substantially perpendicular to the longitudinal axis of the elastomeric element 203b, and is sized to accommodate a UT transducer in the same orientation. Twelve UT transducers 211, 213 are accommodated in the radial bores and are mounted in threaded bores in the housing 202 and are connected to the control/processing

system 220 by electrical wires 210 and 212. Each UT transducer is thus fixed in position relative to the housing 202. The working face of each UT transducer abuts the elastomeric element 203. In this way the coiled tubing 201 is substantially circumferentially surrounded by UT transducers 211, 213. Each UT transducer is capable of emitting compression waves at 2.25MHz from a composite crystal with a 12.7mm (0.5″) diameter working face with a focal spot of about 10mm (0.4″) in diameter at about 6-7mm from the tubing. The ultrasonic waves are emitted substantially perpendicular to the outer wall of the elastomeric element 203 so as to travel toward the coiled tubing along the shortest path through the elastomeric element 203.

Between each radial bore is a longitudinal bore that is parallel to the longitudinal axis of elastomeric element 203b. Each longitudinal bore accommodates a pull-rod 221, each end of which is connected to plates 226. Each plate 226 takes the form of an annular disc, one positioned at one end of the elastomeric elements 203 and 203b and the other positioned at the opposite end. The upper plate 221 (in the sense of Fig. 8) has threaded recesses by means of which the pull rods are connected thereto. The lower plate 221 (in the sense of Fig. 8) has six piston and cylinder arrangements 222 (only one shown in Fig. 8) disposed around its circumference and on its outer side, into which each pull rod extends and is connected respectively. A fluid supply line 224 is connected to each cylinder for supplying fluid into a chamber defined by the piston, cylinder and plate 226. An O-ring 223 provides a fluid-tight seal between the piston and cylinder.

To inhibit damage to the coiled tubing 201 by the plates 226 an annular plastic bushing 225 is positioned adjacent the inner edge of the plates 226.

At the upper end (in the sense of Fig. 8) of the housing 202 two inductive sensors 228 and 229 are mounted co-axially with their longitudinal axis perpendicular to the longitudinal axis of the coiled tubing 201 (as it passes, in use, through the apparatus 800) on opposite sides thereof. Suitable inductive sensors 228 and 229 are available from Turck Inc. (www.turck-usa.com), Minneapolis, USA, under part number Bi10-M30-LIU that have a nominal sensing range of between 3mm and 8mm. The inductive sensors 228 and 229 can measure the distance between the outer surface of the coiled tubing 201 and the each sensor.

In use, the apparatus 800 is opened and placed around the coiled tubing 201 to be inspected. The coiled tubing may be inspected during insertion into a wellbore, upon withdrawal from the wellbore or at the coiled tubing manufacturing facility for example. The apparatus is closed around the coiled tubing and the latches closed and tightened, thereby bringing the elastomeric element 203 into contact with part of the coiled tubing. Hydraulic fluid is supplied to the pistons and cylinders 222 via fluid line 224. One advantage of application of pressure hydraulically is that an operator can adjust it remotely during the testing procedure without the need to reach the apparatus 800. Filling of the aforementioned chamber with fluid causes the lower plate 226 to be urged upwardly (in the sense of Fig. 8) and the piston 222 to be urged downwardly. By virtue of the connection between the piston 222 and the upper plate 226 by the pulling rods 221, the upper plate 226 is urged downwardly (in the sense of Fig. 8) toward the lower plate 226. Thus both elastomeric elements 203 and 203b are compressed between the plates 226. The application of pressure causes a slight deformation of the elastomeric element 203 such that it is pressed both against the pipe and working

faces of the UT transducers to couple the same together for the purposes of ultrasonic testing. In doing so the elastomeric element 203 substantially adapts to the shape of that part of the coiled tubing with which it is in contact and, as the coiled tubing is passed therethrough, deforms dynamically to reflect any change in that shape.

The applicant has found that the application of pressure onto the elastomeric elements 203 and 203b (and therefore onto the coiled tubing 201), and onto the working faces of the UT transducers of about 3.4×10^6Pa (500psi) or higher is sufficient to induce good ultrasonic coupling between the UT transducers and the coiled tubing 201 at 2.25Mhz. The applicant has also found that ultrasonic coupling begins, but is intermittent, at about 2.1×10^6Pa (300psi) and improves up to about 3.4×10^6Pa (500psi) where full coupling is usually achieved. Above 3.4×10^6Pa it appears that the ultrasonic coupling is not improved by application of greater pressure. It is to be noted that these are the actual pressures in the elastomeric elements. With the apparatus 800 it is necessary to supply between 4.1×10^6Pa (600psi) and 5.5×10^6Pa (800psi) in the actual hydraulic supply to the pistons to achieve these pressures in the elastomeric elements. The limiting factor is that pressure at which the UT transducers are crushed by the elastomeric element 203b. The applicant has found that commercially available UT transducers (e.g. from US Ultratek, Inc. www.usultratek.com) that are able to emit ultrasound at 2.25MHz can withstand the 3.4×10^6Pa pressure required for good coupling. The pressure on the elastomeric elements 203 and 203b is maintained continuously during testing.

The coiled tubing 201 is now moved through the apparatus 800, for example when it is being inserted into or withdrawn from a wellbore. Typically, the coiled

tubing is inserted or withdrawn from a wellbore at about 0.76ms^{-1} (150ft/min) or less, but sometimes up to about 1.27ms^{-1} (250ft/min). In this case the apparatus 800 may be positioned adjacent the levelwind (the assembly that guides the coiled tubing onto and off the reel). The advantages of this are that it is away from the well, it is easily accessible for installation and removal, and while running into the well it provides an early indication of a tubing fault. In such a position, a lubrication device to apply oil, for example, may be required to help the tubing pass through the apparatus. Alternatively, the apparatus may be positioned just above the stripper at the entrance to the well with the advantage that it can remain mounted between coiled tubing operations and lubrication may be easier or even not necessary.

The elastomeric element 203 performs three functions. Firstly it provides a bearing surface for the coiled tubing 201 as it passes through the apparatus 800. The applicant has found that a length of approximately 64mm (2.5″) provides a good balance between weight and the bearing function. If it is made longer, the apparatus 800 must also be longer increasing weight and bulk. If it is made much shorter the apparatus may become skewed on the pipe in use. The second function is to provide a coupling between the UT transducers and the coiled tubing for the purposes of ultrasonic testing. This is achieved by deformation to press the elastomeric element 203 against the ultrasonic transducer means and the tubing. The third function is to respond by deformation or by flexing to the shape of the pipe under test. As the UT transducers are fixed relative to the housing 202, the elastomeric element 203 must adapt substantially to the shape of the portion of the pipe being inspected so that changes can be detected by the UT transducers. Any

elastomeric material capable of performing these functions may be used.

The twelve UT transducers 211, 213 are pulsed 100 times per second to measure the outer diameter, ovality and wall thickness of the coiled tubing at the same frequency. An ultrasonic frequency of between about 2.00MHz and 3.5MHz is useable, with 2.25MHz having produced good results. The applicant has found that the lower the frequency the less accurate the wall thickness measurement of the tubing. However, if the frequency is increased beyond about 3.5Mhz the sound is attenuated too heavily in the elastomeric material. Thus a balance needs to be struck between accuracy and attenuation. The applicant has found that, for this material, this above range produces satisfactory results. If the output signals are not of good quality an operator may adjust the pressure applied to the elastomeric elements by means of fluid line 224 in an attempt to improve the ultrasonic coupling. Usually this will be by increasing the applied pressure, in case the elastomeric material is not yet beyond the full coupling pressure. The applicant has also found that elastomers are not good conductors of sound, with attenuation (in dB/mm) increasing with frequency. Thus although a higher frequency could be used in principle, the received signal is weaker in amplitude and therefore the important signal characteristics are harder to pick out that enable outer diameter, ovality and wall thickness to be determined.

Each pulse of ultrasound passes through the elastomeric element 203, into the coiled tubing 201 and is reflected from the inner surface of the coiled tubing from where it travels back toward the UT transducer. The UT transducer receives the reflected sound and generates and electrical output signal, an example of which is shown in Fig. 9 generally identified by reference numeral

900. The first part 901 of the reflected signal at about 0 to 4µs is repeated reflection within the UT transducer itself. The second part 902 at about 4-11µs is reflection from the transducer/elastomer interface. The first reflection 903 from the elastomer/coiled tubing interface occurs at about 18µs. The coiled tubing 201 is constructed from steel that is a very good conductor of sound. Once the sound enters the coiled tubing 201 it bounces back and forth between the inner and outer wall. Each time the sound strikes the outer wall part is transmitted onto and is picked up by the UT transducer and part is reflected back. This repeated reflection results in a "ringing" 904 (also known as a "Christmas tree" in the art due to its characteristic shape) between about 20-33µs, seen as a periodic signal of gradually decaying amplitude at the UT transducer.

From this signal it is possible to determine the ovality, outer diameter and wall thickness as described below. In order to determine the diameter of the pipe, the part 903 of the signal is the portion of interest. It will be recalled that there are twelve UT transducers corresponding to six pairs of diametrically opposed UT transducers. In the closed position of the apparatus 800, the distance D between the opposed faces of the six pairs of UT transducers can be measured before testing. Thus, by determining the distance d_1 between one UT transducer and the outer surface of the coiled tubing 201, and the distance d_2 between the diametrically opposite UT transducer and the coiled tubing 201, the outer diameter d of the coiled tubing between that pair of UT transducers is given by: -

$$d=D-(d_1+d_2)$$

A series of gates 905, 906, 907, 908 are applied to the electrical signal output. The gate 905 at about 12µs serves as a marker before which the signal is ignored.

Software monitoring the signal sets the second gate 906 at the first large signal after the first gate 905, in this case at approximately 18µs, although the applicant has found that this can be anywhere between about 7µs and 33µs depending on the thickness and temperature of the elastomeric element 203. The time of the second gate 906, corresponding to the reflection from the outer surface of the coiled tubing 201, enables the distance from the UT transducer to the outer surface to be determined by multiplying the speed of sound in the elastomer by this time.

The applicant has encountered a problem in measuring this distance during use of the apparatus. This is because the speed of sound V_e in the elastomer changes with temperature and is therefore not known at the instant in time the measurement is made. When the apparatus is first used the elastomeric element may be relatively cool. As coiled tubing 201 passes through the elastomeric element 203, it is heated by friction, bearing in mind that the elastomeric element 203 is urged against the coiled tubing and performs a bearing function. Thus a temperature gradient is established across the elastomeric element 203 between the UT transducer and the elastomer/coiled tubing interface. This temperature gradient may vary dynamically according to coiled tubing speed, temperature and wetness for example. As elastomers are good insulators, the applicant believes that the temperature gradient can be significant such that the speed of sound across the elastomeric element 203 is not constant. This leads to error in the measurement of the distance between the UT transducer and the elastomer/coiled tubing interface. In order to overcome this it might be possible to measure the temperature of the elastomeric element 203 and compensate accordingly, or to measure V_e to calibrate the distance

measurement. However, this is not straightforward due to the existence of the temperature gradient as described above.

The applicant has solved the problem by provision of the two electromagnetic induction sensors 227 and 228 capable of proximity measurement. In use, the two sensors 227, 228 measure their respective distance to the pipe. In combination with the time measurements made by the corresponding UT transducers (i.e. those in alignment around the longitudinal axis of the pipe), these two measurements can be used to determine an average V_e in the elastomeric material for the temperature gradient at that moment in time. This average V_e can then be used to calculate the twelve distances between the twelve UT transducers and coiled tubing using the time measurements of the gate 906. In this way, no actual temperature measurements need to be taken and the UT transducers are dynamically calibrated so that the apparatus can be used to obtain accurate measurements during insertion or withdrawal of the coiled tubing 201 into a wellbore. In this way, variation in the temperature gradient (and therefore of V_e) is automatically taken into account in determining outer diameter.

One disadvantage with this calibration method is that the sensors 227 and 228 measure distance about 3 inches away from the UT transducers 211, 213. Therefore the sensors are not measuring exactly the same diameter as the UT transducers. If an abrupt diameter change were to pass through the apparatus, it may be that the distance measured by the UT transducers is significantly different to that measured by the sensors 227 and 228. As the applicant believes that, in use of the apparatus, the temperature gradient in the elastomeric element 203 will not change instantly, a rolling time average of the average speed should mitigate this problem. Therefore V_e

is averaged over time (e.g. 1-3s); the applicant has found in experiments that by using the time average of V_e this small axial separation does not affect the results obtained, when a sudden diameter change (e.g. butt weld on the tubing) is encountered.

The outer diameter of the coiled tubing between each pair of UT transducers can therefore be determined as follows: -

$$d=D-\tfrac{1}{2}(t_{p1}+t_{p2})$$

where t_{p1} and t_{p2} are the times of the signal 903 at each UT transducer respectively, and remembering that the ½ results from the fact that the sound has travelled to the outer surface of the coiled tubing and back to the UT transducer.

Thus the apparatus 800 takes six diameter measurements, one hundred times per second as the coiled tubing 201 moves past the UT transducers 211, 213. The diameter measurements can be output and stored in electronic format, for example in computer memory.

From the six diameter measurements, the ovality of the coiled tubing at the point of test can be determined as follows: -

$$\%\text{Ovality} = 100((D_{max}/D_{min})-1)$$

where the nearer to zero %Ovality is, the more round the coiled tubing is at that point. The ovality results can be output and stored in electronic format, for example in computer memory.

In order to determine the wall thickness of the coiled tubing 201, two further gates 907 and 908 are set on the received signal in Fig. 10. Gate 907 is set 3-4µs from the gate 906. This is to avoid the noisy part of the signal associated with the reflection from the outer surface of the coiled tubing. The gate 908 is set 5-6µs from the gate 907. This time is based on experience gained by the applicant by experiment and is sufficient

to contain several reflections from the inner and outer surfaces, but before the signal becomes too small to be useful and before any further reflection from the elastomer/pipe interface is received. After the first reflection 906, some of the ultrasound returning to the UT transducer is reflected back toward the pipe, resulting in a further reflection from elastomer/pipe interface. It is important set gate 908 before such further reflections are received.

The signal is analysed by software to determine the time T between reflections from the inner and outer surfaces, remembering that only the reflection from the inner surface of the coiled tubing is seen by the UT transducer. When the ultrasound travels toward the outer surface in the direction of the UT transducer, no reflected component from the outer surface is seen by the UT transducer because the component reflected from the outer surface travels back toward the inner surface. Thus only reflections from the inner surface are received by the UT transducer.

Accordingly the time period T between peaks of the ringing 904 represents the time taken for the ultrasound to travel from the inner surface to the outer surface and back to the inner surface i.e. twice the wall thickness. One way to determine the time period T is to draw a line 909 through the middle of the 'Christmas tree'; find the first and last times t_1 and t_2 that the signal crosses the line with a positive gradient; count the number of times n that the signal crosses the line (both positive and negative gradient) between t_1 and t_2, including t_1 and t_2; T is then given by: -

$$T=2(t_2 - t_1)/(n-1)$$

An alternative way to find T is to make a copy of the signal between gates 907 and 908; estimate T; shift the wave by T/2; add the signal and shifted copy signal

together; the summed signal is the error in T, with a zero signal indicating that T is correct. This process can be iterated by adding or subtracting fixed amounts to the estimated value of T and repeating the process. This may be done twenty times for example and the smallest error signal taken as the actual value of T. This method has limitations as it assumes that the received signal is symmetrical (e.g. a sine wave) which very often it is not. However, the applicant has found that results for T produced in this way are satisfactory.

Once a value for T has been determined, the wall thickness W can be determined by: -

$$W=\tfrac{1}{2}TV_S$$

where V_S is the velocity of sound in steel (or whatever the coiled tubing is constructed from).

Thus twelve wall thickness measurements are made, one hundred times per second as the coiled tubing 201 moves through the apparatus 800.

The applicant has found that, sometimes, the UT transducer receives no reflected ultrasound. Investigation revealed that this is when the longitudinal seam weld of the coiled tubing is under that transducer. The evidence of the weld is usually removed from the outer surface of the coiled tubing during manufacture, whereas the evidence on the inner surface is usually (although not always) left in place. As coiled tubing rotates during its working life e.g. during a drilling application, it is difficult to know whether or not the coiled tubing returns on to the reel in the same rotational orientation as when it left the reel. This information would be very useful for bending fatigue considerations that could be included when considering whether or not particular tubing has exceeded its working life. At present the worst scenario is assumed i.e. that all bending takes place in the same plane. This may

result in some tubing being wasted that has potential extra working life.

Thus the wall thickness data enables the rotational orientation of the tubing to be determined, once the longitudinal seam weld has passed under a transducer and no wall thickness determination can be made. In this case, the rotational orientation is either known exactly (i.e. when it is under a transducer) or, if it has moved away from that transducer but has not affected either adjacent transducer, it can be said to be within ±30° of that transducer. This is a considerable improvement over existing knowledge based on measurements with UT transducers and this rotational orientation data can be taken into account when estimating working life and/or suitability of coiled tubing for a particular task.

The applicant has found that the 12.7mm (0.5″) thick elastomeric element 203 produces good results over the applied pressure range mentioned at a frequency of 2.25MHz. A useful working range of thicknesses with this elastomer has been found to be about 9.5mm (3/8″) to 15.9mm (5/8″). If the material is any thinner than this repeated reflections between the UT transducer and the outer surface of the coiled tubing are received before the ringing in the pipe has been fully detected and recorded. This makes it difficult or impossible to read the period T of the 'Christmas tree' which is needed to determine wall thickness. On the other hand, if the material is any thicker the ultrasound is attenuated too heavily in the elastomeric element 203. Furthermore, for a given focal length transducer, moving working face nearer and further from the tubing increases and decreases respectively the size of the "spot" of ultrasound on the tubing. It is desirable to have this spot as small as possible to increase the accuracy of wall thickness measurements. Therefore, for a given focal

length transducer, it should be further away from the tubing to localise measurements as much as possible. However, when a thicker elastomeric element is used the ultrasound is attenuated too heavily. Conversely when it is thinner, the received signal is improved, but accuracy is sacrificed as the size of the spot is increased. The applicant has found that a 10mm spot is sufficient to give the necessary accuracy; this can be given by a elastomer thickness of about 12.7mm, as explained above.

Thus, whatever material is chosen for the elastomeric element 203, it should be capable of transmission of force onto the coiled tubing to provide an ultrasonic coupling function; be elastically flexible or deformable so as to absorb changes in diameter and shape of the coiled tubing so that those changes may be detected by ultrasonic inspection; have a thickness such that the output signal representing ultrasound received at the UT transducer has substantially only one electronically identifiable reflection from the outer surface of the coiled tubing followed by an electronically identifiable periodic signal of decaying strength representing ultrasound being repeatedly reflected from the inner and outer surface of the coiled tubing, so that the period of those reflections, and thereby the thickness of the wall of the coiled tubing, may be determined.

It will be noted that the elastomeric element 203 is of a higher hardness (durometer) than the elastomeric element 203b. This enhances the performance of the apparatus 800. In particular, the applicant has found that a harder material is useful for the elastomeric element 203 as it must function as a bearing surface for movement of the coiled tubing, whilst also providing the coupling between the UT transducers and the tubing. However, the elastomeric element must not be too hard;

otherwise it will not absorb and deform to changes in shape of the coiled tubing. Ideally the elastomeric element 203 has a low coefficient of friction together with a high hardness value.

In contrast the elastomeric element 203b is of a lower durometer than the elastomeric element 203. This enables it to be squeezed more easily between the plates 226 and thereby apply pressure onto the element 203. Importantly, a softer element 203b works in combination with the harder element 203 so that the competing requirements of ultrasonic coupling, provision of a bearing surface and sufficient flexibility to conform to the shape of the coiled tubing can be accommodated. The softer element 203b also provides a shock absorbing function when larger diameter portions of the tubing (e.g. butt weld) pass through the apparatus. Furthermore, the elastomeric element 203 wears with time and the provision of two separate elastomeric elements means that the element 203 can be replaced easily.

As explained above, the thickness of the elastomeric element can be varied by approximately ±3.2mm (1/8″) without loss of functionality of the invention. Thus the elastomeric element 203 can be replaced by other thicker or thinner elements to accommodate a range of coiled tubing outer diameters e.g. from 38.1mm (1.5″) to 44.5mm (1.75″) without having to change the apparatus 800 for a larger or smaller version. Additionally or alternatively, the length of the UT transducers may be changed to accommodate different outer diameter coiled tubing with appropriate thicknesses of the elastomeric elements 203 and 203b.

As an additional or an alternative to the apparatus 800, UT transducers that are not radially disposed around and perpendicular to the longitudinal axis of the coiled tubing may be incorporated into the apparatus 800, or any

other apparatus disclosed herein. Such UT transducers may be oriented to introduce ultrasound into the coiled tubing to travel around the circumference searching for longitudinally oriented defects and/or the longitudinal seam weld. In this way defect inspection is also performed and the rotational position of the longitudinal seam weld can also be monitored with improved accuracy. Furthermore such UT transducers may be oriented to introduce ultrasound to travel longitudinally along the tubing and/or at an oblique angle to inspect for cracks and other defects. In any event, the same elastomeric coupling mechanism described above may be utilised with appropriate adjustment to introduce the ultrasound at the correct angle relative to the surface of the tubing (typically approximately 60°).

It is within the scope of this invention to use one or a plurality of areas of increased or decreased wall thickness on pipe, tubulars or coiled tubing for use in wellbore operations, and to position one or more of such areas at known locations so that, upon sensing of the presence of the area(s), the amount of pipe, etc. and/or the location of an item thereon can be accurately calculated and/or displayed. For example, positioning an area of increased wall thickness with a known wall thickness that acts as a suitable signature for that area a thousand feet above the end of coiled tubing makes it possible for an operator to know when a thousand feet of the coiled tubing has been inserted into a wellbore and, in retrieving the coiled tubing from the wellbore, to know when there is still a thousand feet left in the wellbore to be retrieved. Positioning an area of known increased or decreased wall thickness at a known distance from an apparatus or device on a tubular string permits accurate locating of the device within the wellbore and/or provides an accurate indication of the location.

Similarly, the depth of a wellbore and/or of the end of string can be determined by using one or more areas of known sensible wall thickness at known locations on a tubular string. In one aspect, a sensible area of known and/or unique wall thickness near the end of coiled tubing provides an indication to an operator that the end of the tubing is near as it is being withdrawn from a wellbore so that appropriate action can be taken, e.g., slowing down of the rate of tubing retrieval to prevent damage to equipment. Naturally occurring areas or rings of different wall thickness can, within the scope of the present invention, be used as the areas or rings described above. In other embodiments a series of spaced-apart areas or rings of a wall thickness are used that differ from the areas on either side of the series and such areas or rings can be of the same or of different wall thicknesses themselves. In one aspect simply the number of areas or rings of different wall thickness is used to provide a locating function.

Force may be applied substantially radially to the elastomeric elements to achieve ultrasonic coupling. With appropriate structural design it is envisaged that the UT transducers themselves might be urged onto the elastomeric element 203, which in turn is pressed onto the tubing, to provide coupling. This may be instead of or in addition to force applied to the elastomeric elements. However, it is expected that this would not be desirable as accidental application of too much force could risk damaging or destroying the transducer.

CLAIMS: -

1. An apparatus for inspecting a tubular with ultrasound, which apparatus comprises means for mounting an ultrasonic transducer means on the apparatus adjacent an ultrasonic coupling means, the arrangement being such that, in use, ultrasound can be introduced into the tubular via said ultrasonic coupling means, characterised in that said ultrasonic coupling means comprises a deformable element and by means for applying a force to said deformable element to enhance the coupling between the ultrasonic transducer means and the tubular.

2. An apparatus as claimed in claim 1, wherein said deformable element is such that, under application of said force, it is urged against a working face of an ultrasonic transducer means and it substantially conforms to part of the shape of said tubular whereby changes in said shape may be detected by said ultrasonic transducer means.

3. An apparatus as claimed in claim 1 or 2, wherein said deformable element has a thickness across which ultrasound passes in use, the thickness being such that, at an ultrasonic transducer means capable of receiving any ultrasound reflected from an outer surface of the tubular and generating an electrical signal representative thereof, an electronically identifiable periodic signal of decaying strength representing ultrasound being repeatedly reflected between an inner and the outer surface of the tubular is received between signals representing ultrasound being reflected from the outer surface of the tubular.

4. An apparatus as claimed in claim 3, wherein said thickness is such that only one electronically identifiable reflection from the outer surface of the tubular is received before said periodic signal of decaying strength.

5. An apparatus as claimed in claim 3 or 4, wherein said thickness is between approximately 9.5mm and 15.9mm.

6. An apparatus as claimed in claim 5, wherein said thickness is approximately 12.7mm.

7. An apparatus as claimed in any of claims 1 to 6, wherein, in use, said deformable element is annular to substantially surround the circumference of said tubular.

8. An apparatus as claimed in preceding claim, wherein in use, said tubular is moved relative to said apparatus to provide for inspection of the tubular along its length and said deformable element provides a bearing surface for that movement.

9. An apparatus as claimed in any of claims 1 to 8, wherein said deformable element comprises an elastomeric material.

10. An apparatus as claimed in claim 9, wherein said elastomeric material is a polyurethane.

11. An apparatus as claimed in any of claims 1 to 10, wherein said deformable element comprises a first deformable element adjacent a second deformable element, the arrangement being such that, in use, said first deformable element is positioned in abutment with the tubular and the second deformable element is positioned to provide support to the first deformable element.

12. An apparatus as claimed in claim 11, wherein said first deformable element has a first hardness and said second deformable element has a second hardness, the first hardness being greater than said second hardness, whereby the first element provides the ultrasonic coupling function and the second element facilitates response of the first element to changes in shape of the tubular.

13. An apparatus as claimed in claim 12, wherein said second deformable element has a one or more holes through which, in use, one or more ultrasonic transducers may be

inserted to be substantially in abutment with said first deformable element.

14. An apparatus as claimed in claim 13, wherein said first deformable element comprises a substantially cylindrical inner surface for abutment with the tubular, and a plurality of substantially flat portions on its outer surface with which one or more ultrasonic transducers may be brought into abutment.

15. An apparatus as claimed in claim 14, wherein said second deformable element comprises a substantially cylindrical outer surface, and a plurality of substantially flat portions on its inner surface for co-operation with said plurality of flat portions on said first deformable element.

16. An apparatus as claimed in any preceding claim, further comprising a housing in which said deformable element is mounted, said housing being substantially cylindrical in shape and formed in two halves that are pivotally mounted together about an axis substantially parallel to a longitudinal axis of the housing, whereby the apparatus is moveable between an open position in which it may be placed around the tubular and a closed position in which said deformable element is brought into abutment with the tubular for testing, said deformable element being formed in two halves, each half being mounted in a respective half of said housing.

17. An apparatus as claimed in any preceding claim, wherein said means for applying a force to the deformable element can apply a force such that said deformable element is urged substantially radially inwardly against said tubular.

18. An apparatus as claimed in any preceding claim, wherein said force can be applied to said deformable element in a direction substantially parallel to a longitudinal axis of the deformable element.

19. An apparatus as claimed in claim 18, wherein in use, said longitudinal axis is substantially parallel to a longitudinal axis of the tubular.

20. An apparatus as claimed in any preceding claim, wherein said means for applying force can apply a compression force to the deformable element to cause a deformation of said deformable element in a substantially radial direction toward the tubular such that the deformable element is compressed against the surface thereof.

21. An apparatus as claimed in any preceding claim, wherein said means for applying force comprises a member in abutment with a part of said deformable element, said member being moveable to apply a compression force thereto.

22. An apparatus as claimed in any of claims 17 to 21, further comprising fluid supply means for controlling the force applied to said deformable element, whereby said force may adjusted remotely from said apparatus during use so as to enhance the ultrasonic coupling provided by said deformable element.

23. An apparatus as claimed in claim 21 or 22, wherein said member comprises a first member and a second member positioned at opposite ends of the deformable member, wherein said first and second members are moveable relative to one another to compress said deformable element therebetween.

24. An apparatus as claimed in claim 23, wherein said first and second members are connected by a plurality of pull rods, each pull rod being connected to a piston housed in a cylinder, and the fluid supply means is in fluid communication with a chamber defined by the piston and cylinder, the arrangement being such that, in use, fluid supplied to said chamber causes said first and second members to be drawn toward one another.

25. An apparatus as claimed in any preceding claim, wherein said means for applying a force can apply a force to said deformable element resulting in a pressure applied to the tubular element of approximately 2.1×10^{6}Pa or greater.

26. An apparatus as claimed in any preceding claim, further comprising proximity measuring means for, in use, measuring a distance corresponding to the distance between the ultrasonic transducer means and the tubular, whereby the ultrasonic transducer means may be calibrated.

27. An apparatus as claimed in claim 26, wherein said proximity measuring means are mounted in a position spaced axially along the tubular relative to the ultrasonic transducer means, but in approximately the same rotational orientation as the ultrasonic transducer means around the tubular.

28. An apparatus as claimed in claim 26 or 27, wherein said proximity measuring means comprise an electromagnetic induction proximity sensor.

29. An apparatus as claimed in claim 26, 27 or 28, wherein proximity measuring means comprise two diametrically opposed sensors mounted with their longitudinal axes substantially perpendicular to the longitudinal axis of the tubular when it is in the apparatus.

30. An apparatus as claimed in any preceding claim, further comprising an ultrasonic transducer means for transmitting ultrasound into and/or receiving ultrasound from said deformable element.

31. An apparatus as claimed in claim 30, wherein said ultrasonic transducer means is mounted in a substantially fixed frame of reference such that changes in the shape of the tubular are manifested in a change in the distance between the ultrasonic transducer means and an outer

surface of the tubular.

32. An apparatus as claimed in claim 30 or 31, wherein said ultrasonic transducer means comprise a plurality of ultrasonic transducers arranged substantially around a circumference of said deformable element for transmitting ultrasound in a substantially radial direction toward said tubular.

33. An apparatus as claimed in claim 30, 31 or 32, wherein said ultrasonic transducer means can transmit ultrasound at a frequency between approximately 2.0MHz and 3.5MHz.

34. An apparatus as claimed in claim 33, wherein said frequency is 2.25MHz.

35. For use in an apparatus of any preceding claim, a deformable element comprising the deformable element features of any of claims 1 to 15.

36. For use in an apparatus according to any of claims 1 to 34, a first deformable element comprising the first deformable element features of any of claims 11 to 15.

37. For use in an apparatus according to any of claims 1 to 34, a second deformable element comprising the second deformable element features of any of claims 11 to 15.

38. A method of inspecting a tubular with ultrasound using an apparatus according to any of claims 1 to 34, which method comprises the steps of: -

(1) introducing ultrasound with an ultrasonic transducer means into the tubular via an ultrasonic coupling means;

(2) receiving via the ultrasonic coupling means any ultrasound reflected from a part of the tubular and generating an output electrical signal representative thereof;

characterised in that said ultrasonic coupling means comprises a deformable element and by the step of applying a force to said deformable element to enhance

the coupling between the ultrasonic transducer means and the tubular.

39. A method as claimed in claim 38, further comprising the step of introducing ultrasound in a direction substantially radially toward the tubular and perpendicular to its longitudinal axis, whereby said output electrical signal can be used to determine at least one of the outer diameter of the tubular, the inner diameter of the tubular, the ovality of the tubular and the wall thickness of the tubular.

40. A method as claimed in claim 38 or 39, further comprising the step of calibrating said ultrasonic transducer means by taking a measurement to estimate the speed of sound in the deformable element, whereby any temperature variation in the deformable element is taken into account.

41. A method as claimed in claim 40, wherein said measurement is a distance corresponding to a distance between the ultrasonic transducer and the tubular, the method further comprising the steps of electronically determining an average speed of sound in the deformable element obtainable by dividing said measurement by the half the time measured by the ultrasonic transducer means for the ultrasound to travel to the outer surface of the tubular and back, said average speed providing a temperature compensated estimate of the speed of sound in the deformable element and useable subsequently to determine the distance between the ultrasonic transducer means and the tubular.

42. A method as claimed in claim 40, further comprising the step of repeating the determination of the average speed periodically and electronically determining a time average of the speed estimate.

43. A method as claimed in any of claims 38 to 42, further comprising the steps of introducing ultrasound at

points around the circumference of the tubular, electronically monitoring said output signals for the absence of ultrasound reflected from an inner surface of the tubular, said absence indicating the presence of a longitudinal seam weld, whereby the rotational orientation of said longitudinal seam weld can be subsequently electronically monitored and the rotational orientation over time electronically stored, for example in an electronically readable memory.

44. A method as claimed in any of claims 38 to 43, further comprising the step of introducing ultrasound into the tubular so as to inspect for defects and welds along the length of the tubular and/or around the circumference of the tubular by reflection of ultrasound between the inner and outer walls.

45. A method as claimed in any of claims 38 to 44, further comprising the step of moving said tubular relative to said deformable element to inspect the tubular along its longitudinal axis.

46. A method as claimed in claim 45, wherein said tubular is a coiled tubing, and the step of moving the tubular is performed by inserting the coiled tubing into or withdrawing the coiled tubing from a wellbore.

47. A method as claimed in claim 45 or 46, wherein said tubular comprises at least one portion of thicker or thinner wall thickness of predetermined dimension, said portion serving as an indication of the position of the ultrasonic transducer means along the length of the tubular, the method further comprising the step of electronically monitoring the wall thickness of the tubular as measured by the ultrasonic transducer means, and outputting an electronic signal when said at least one portion is located.

48. Coiled tubing having a first wall thickness along the majority of its length, and provided with at least

one portion of a second wall thickness different to said first, the second wall thickness useable as indication of the length of the coiled tubing that has been inserted into or withdrawn from a wellbore for example.

49. A method of manufacturing coiled tubing, which method comprises the steps of folding a sheet of material of a first wall thickness and welding the two free sides to form a tubular, and providing portions of a second wall thickness different to said first at predetermined intervals along the length of the coiled tubing to serve as an indication of length when inserting or withdrawing the coiled tubing into or from a wellbore for example.

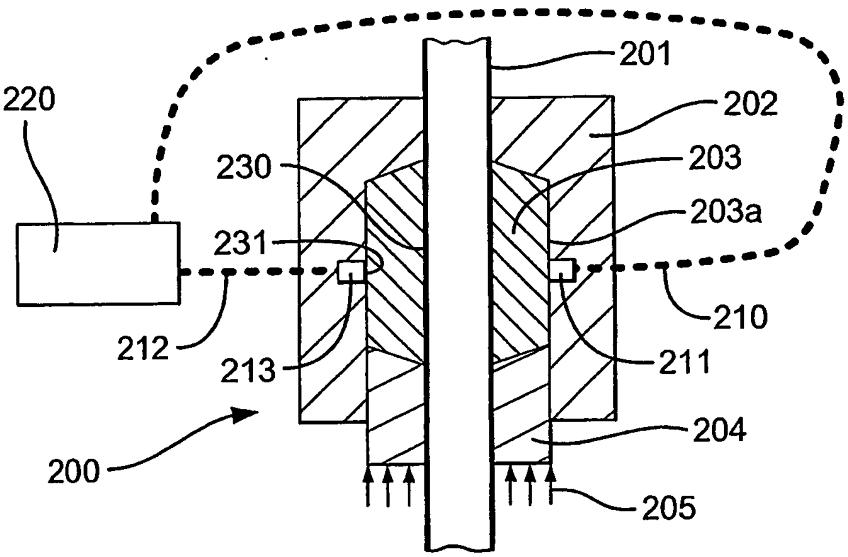

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Fig. 1

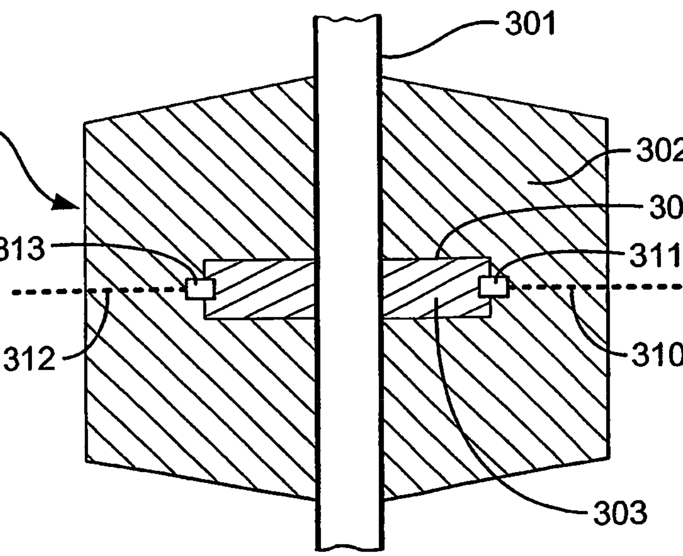
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Fig. 2

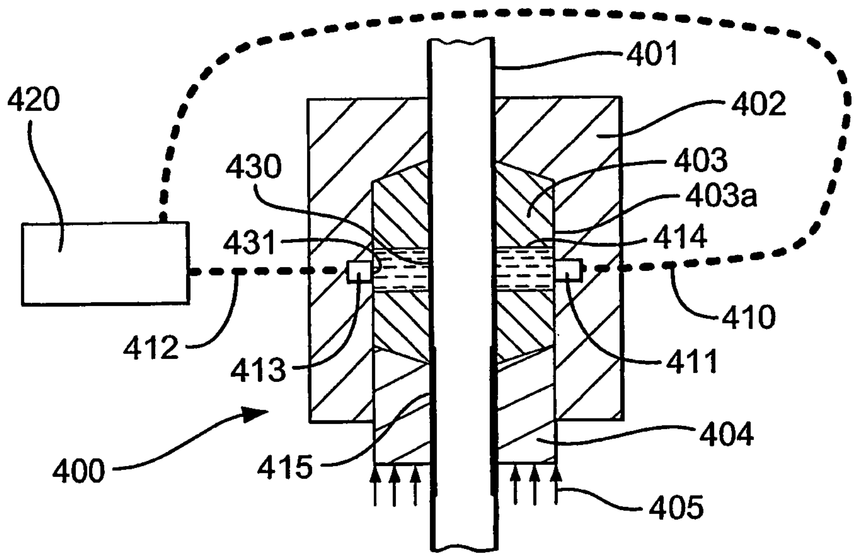
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Fig.3

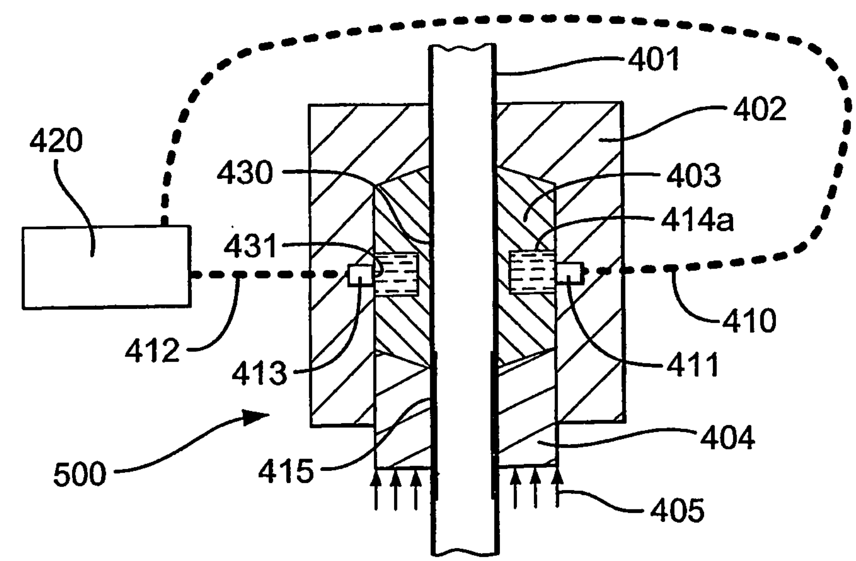
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Fig.4

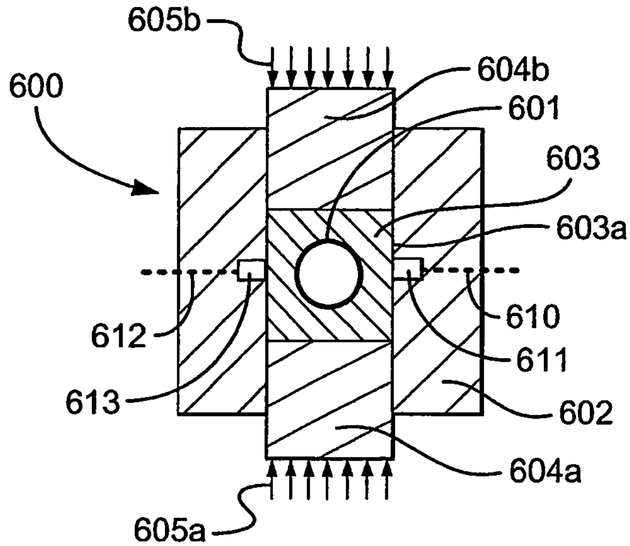
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Fig.5A

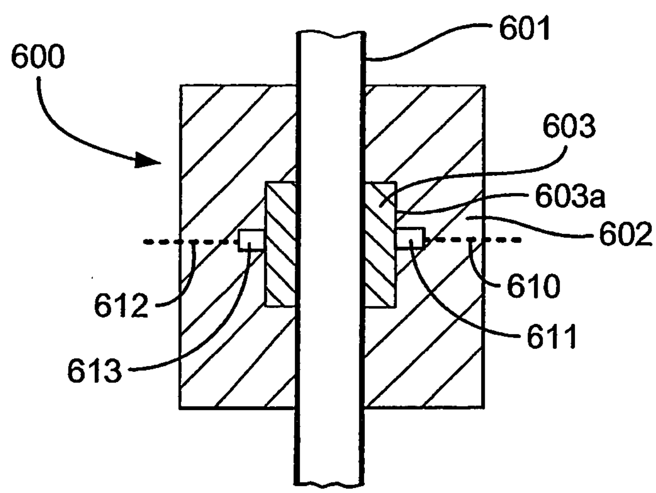
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Fig.5B

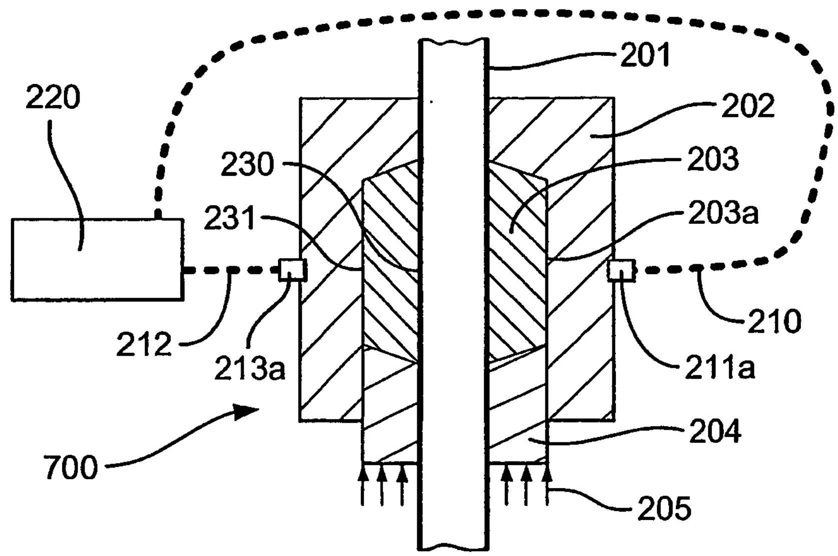

Fig.6

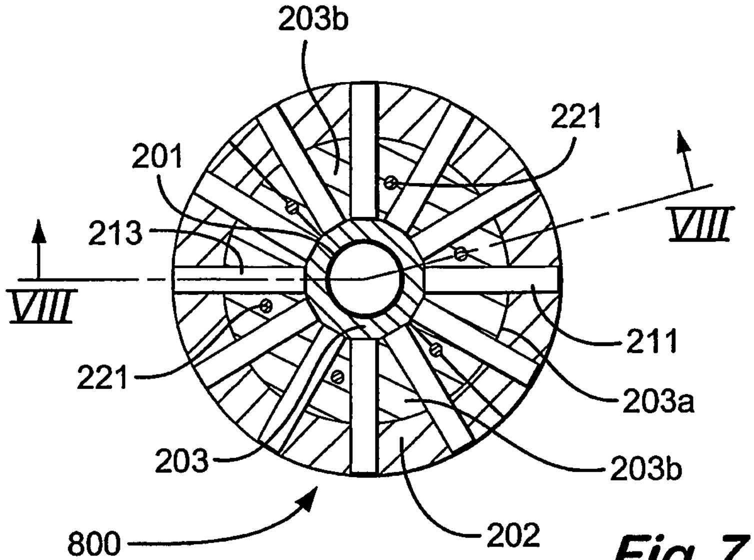
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Fig. 7

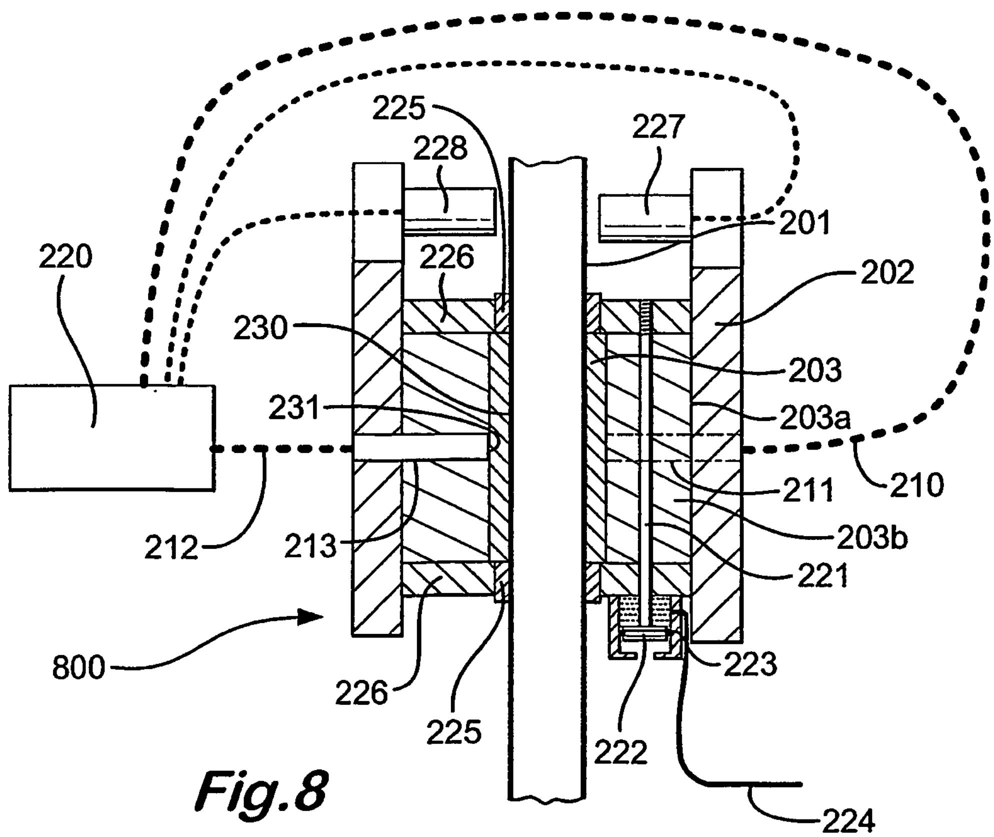
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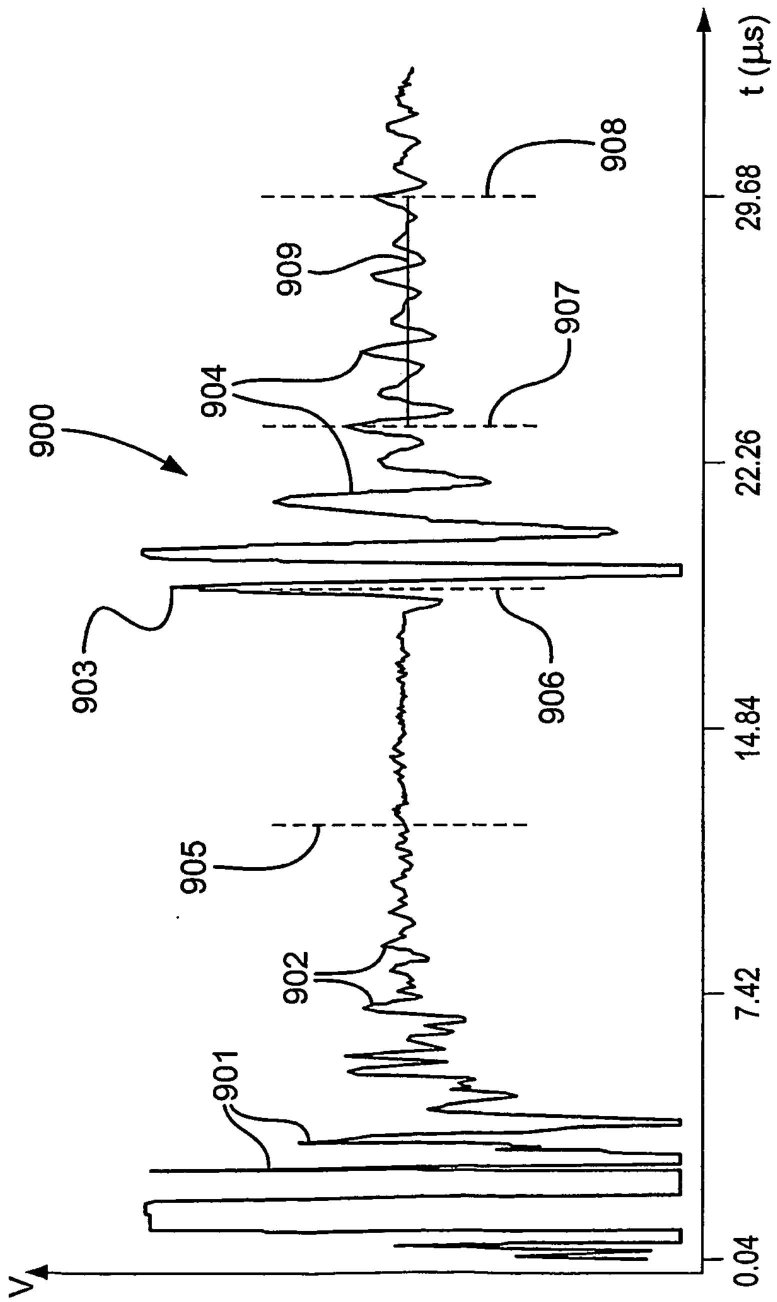
Fig. 8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909
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14.84
22.26
29.68

Fig.9

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 March 2004 (25.03.2004)

PCT

(10) International Publication Number
WO 2004/025291 A3

(51) International Patent Classification[7]: G01N 29/28 // 29/26, 29/10

(21) International Application Number: PCT/GB2003/003986

(22) International Filing Date: 15 September 2003 (15.09.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/243,996 13 September 2002 (13.09.2002) US

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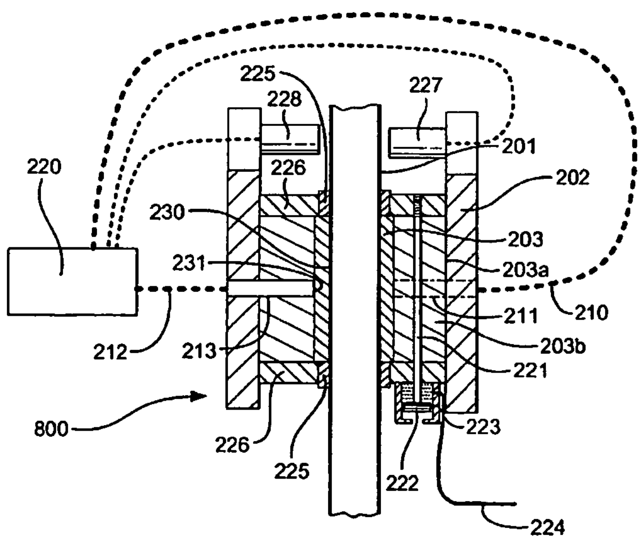
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: AN APPARATUS AND METHOD FOR INSPECTING A TUBULAR WITH ULTRASOUND BY USING A DEFORMABLE ACOUSTIC COUPLING ELEMENT



(57) Abstract: An apparatus for inspecting a tubular with ultrasound, which apparatus comprises means for mounting an ultrasonic transducer means on the apparatus adjacent an ultrasonic coupling means, the arrangement being such that, in use, ultrasound can be introduced into the tubular via said ultrasonic coupling means, characterised in that said ultrasonic coupling means comprises a deformable element and by means for applying a force to said deformable element to enhance the coupling between the ultrasonic transducer means and the tubular.

WO 2004/025291 A3

Declaration under Rule 4.17:
— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(88) Date of publication of the international search report: 1 July 2004

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INTERNATIONAL SEARCH REPORT

PCT/GB 03/03986

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01N29/28
//G01N29/26,G01N29/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 041 773 A (HAULDREN H MORRIS ET AL) 16 August 1977 (1977-08-16)	1,9,17, 20,21, 25,30, 31, 33-39,45
Y	the whole document	2-6,10, 26,28, 32,44,46
A		7,8, 11-16, 18,19, 22-24, 27,29, 40-43,47

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
12 February 2004	10. 05. 2004

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 03/03986

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 718 277 A (GLASCOCK JAMES D) 12 January 1988 (1988-01-12)	1,9,17, 30,31, 35-39,45
Y	abstract; claims 1,1013,17; figures 1,2,5,6	2,10,22, 26,28, 44,46
A	column 2, line 8 - line 58	3-8, 11-16, 18-21, 23-25, 27,29, 32-34, 40-43
	column 3, line 66 - column 6, line 48 column 8, line 35 - column 9, line 25 -----	
X	US 3 921 442 A (SOLOWAY SIDNEY) 25 November 1975 (1975-11-25)	1
Y	abstract; claims 1-6; figures 2,3 column 3, line 10 - column 5, line 40 -----	2
Y	US 5 585 565 A (GLASCOCK JAMES D ET AL) 17 December 1996 (1996-12-17)	2,10,22
A	column 1, line 56 - column 2, line 55 column 3, line 18 - line 20 abstract; claim 1; figures 1-5 -----	1,35
Y	V. DEUTSCH, M. PLATTE, M.VOGT: "Ultraschallprüfung, grundlagen und indutrielle Anwendungen" 1997, SPRINGER , BERLIN HEIDELBERG , XP002270160	3-6,32
A	page 235, paragraph 2 - page 244, paragraph 1; figure 6.24 -----	1,2, 7-31, 33-47
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A	abstract; claim 1; figures 1-6 column 1, line 41 - column 2, line 18 column 2, line 49 - column 3, line 2 -----	7

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 03/03986

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 418 574 A (FLOURNOY NORMAN E) 6 December 1983 (1983-12-06) abstract; figure 1 column 1, line 64 - column 2, line 13 column 3, line 1 - line 13 -----	26,28

Form PCT/ISA/210 (continuation of second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

PCT/GB 03/03986

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-47

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-47

   Apparatus and method for inspection of a tubular using a deformable element for acoustic coupling of the transducer to the tubular. The deformable element being annular and surrounds the circumference of the tubular.

   ---

2. claims: 48,49

   Coiled tubing and method for manufacturing the same having a first wall thickness along the majority of its length and a second wall thickness in a portion of the coiled tubing, the second wall thickness being useable as indication of the length of the coiled tubing that has been inserted into or withdrawn from e.g. a wellbore.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 03/03986

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